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A Modified Single Inductor Boost Converter with Ultrahigh Step-Up Gain

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Abstract:- A modified single-inductor boost converter (MSLBC) can contribute a ultrahigh voltage boosting capability without using any transformer or coupled inductor. This converter topology is highly suitable for applications where better performances, including improved voltage gain, efficiency, power density, and reliability are needed. The major contributions of the MSLBC are ultrahigh voltage boosting capability without using transformer or coupled-inductor, single-inductor structure to realize continuous input current, simple topological structure, lower voltage stress of switches and intrinsic small duty cycle to enhance the system efficiency. Results are obtained by simulating the converter using MATLAB/SIMULINK R2020b.The simulation results shows that the converter has high voltage gain and achieves a peak efficiency of 81%Ṫhe converter is controlled using TMS320F28335 microcontroller. The experimental results obtained from converter prototype confirm the theoretical considerations and the simulation results. The results shows that the modified single inductor boost converter can be used for wide conversion range applications with high voltage gain and low ripple content.

Keywords:- *Boost Converter, Transformer less, High Gain, Efficiency, Single Inductor.*

I. INTRODUCTION

DC-DC converter with high static gain has gained focusin research as there is a requirement of this technology for many applications which generates low dc voltage sources. Boost converters with better performances, including improved voltage gain, efficiency, power density, and reliability, are urgently needed for wide conversion range applications. The proposed single inductor boost converter topology is suitable for renewable energy based applications having low inputdc voltage. This converter topology provides high voltage conversion without using transformer and coupled inductor. The semiconductor power devices used in this topology have reduced voltage stress with low on state resistance. Coupled inductor converters are one of the typical dc-dc converter topology types. Combining with interleaved strategy, a three winding coupled inductor is presented in [1]. With the proper turn ratio of transformers, isolated converters can realize electrical isolation and high voltage gain. In [2], a three-switch isolated boost converter with continuous input current, reduced one active switch, added passive components, and no snubber circuit is analyzed. However, for the no isolated applications, the adopted transformer will increase the system volume, cost, and weight. Adopting the switched-network cells, many dc-dc converters with improved features are analyzed. Combining diode-capacitor circuit with boost and single ended primary inductor converter (SEPIC), a boost converter which has small input ripple, common grounded terminals and limited step-up gain is analyzed in [3]. The dual-switch boost converter in [4] realizes high voltage gain while its topological structure is complex. Comprising the interleaved structure and modified Dickson voltage multipliers, two kinds of boost converters with high voltage gains and small input ripples are analyzedin [5] and [6]. But, the input and output terminals of these two topologies both have no common node. Based on two types of active-passive inductor cells, [7], [8] construct boost convert- ers with extendable structures. Adopting an active switched capacitor network and an active switched inductor network, a boost converter is analyzed in [9]. Combining switched-capacitor/switched inductor cells with traditional switched-boost network, a family of boost converters is presented in [10]. Based on a passive switched-capacitor network and an active switched-inductor network, a boost converter is analyzed in [11]. Z-source and quasi-Z-source structures are also effective methods to construct converters with improved characteristics. Using hybrid switched capacitors switched-inductor method a quasi-Zsource boost converter is analysed in [12] which has improved step-up gain while its input and out- put terminals share no common node. A new single-inductor boost converter (SLBC), which is integrated by the Sheppard- Taylor structure [13] and the switched-capacitor technique is analyzed in [14].

The major contributions of the SLBC are: ultrahigh voltage boosting capability, lower voltage stress of switches and intrinsic small duty cycle to enhance the system efficiency, single-inductor structure to realize continuous inputcurrent and high power density, common grounded terminals to avoid the du/dt issues and achieve reliable output.

A modified single inductor boost converter with high voltage gain is presented. The proposed converter increases the voltagegain with the introduction of a voltage multiplier circuit. Also, the output voltage ripple and the output current ripple are significantly reduced compared to other typical single inductorhigh-gain boost converters. Therefore, the proposed converter reduces the ripple content and improves the voltage gain.

II. METHODOLOGY

Different boost converter topologies are available for different applications. For renewable energy applications, a high gain DC-DC converter with continuous input current is re- quired. A modified single inductor boost converter with ultra- high boosting capability which draws continuous input current with low ripple content is shown in Fig. 1. The topology consists of two synchronously controlled power switches $S_1$and S_2, one input inductor L_1 , four mid capacitors C_1 C_3, load resistor R_0, filter capacitor C_0, five mid-diodes D_1 D_4 and one output diode D_0. D_0.

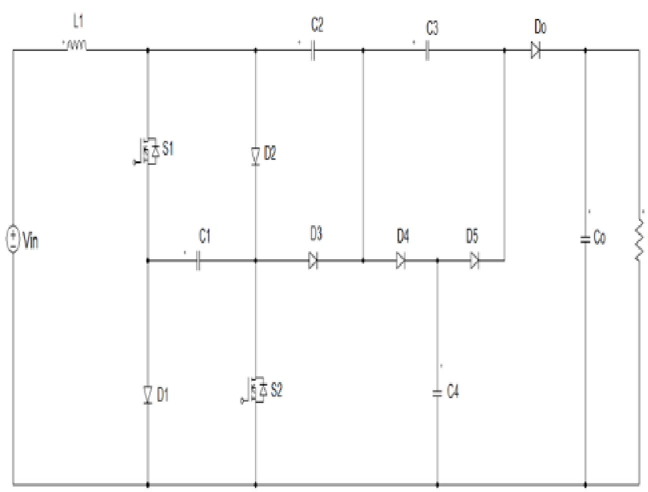

Fig. 1. Transformer less Grid-Connected Boost Inverter

A. Modes of Operation

The proposed single inductor boost converter has two modesin continuous conduction mode basing on the ON-OFF controlactions of switches. In mode I, the power switches S_1 and S_2 are in the ON state, While in the mode II both are in OFFsate. The DC power source is supplied to the inductor L_1 andthe control signal of the switch S_2 is the same as that of the S_1. Fig. 2 shows the theoretical waveforms of boost converter.

1) *Mode 1:* The two synchronously controlled switches S_1 and S_2 together with mid-diodes D_3 and D_5 are turned on and all other diodes and output diode D_0 are turned off in this time interval. There are four circuit loops for the MSLBC operating in mode 1. At this moment the input DC power V_{in}

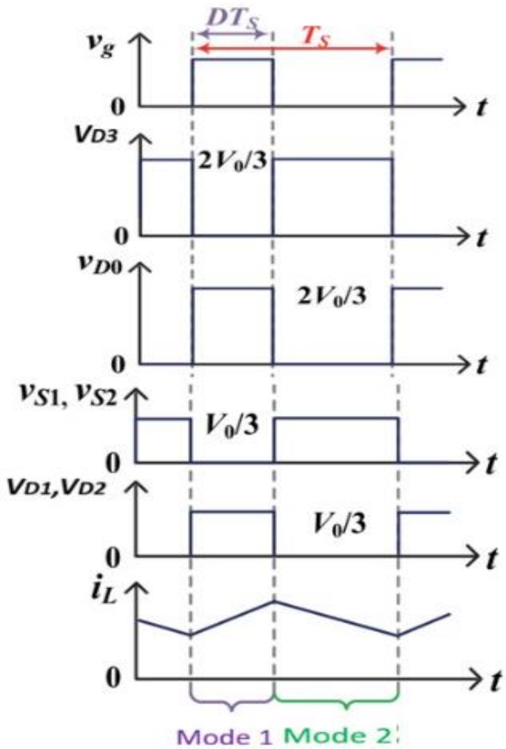

Fig. 2. Theoretical Waveforms of Boost Inverter

and C_1 charges the inductor L_1 through switch S_1 and S_2. The capacitor C_1 and C_4 discharges and charges the capacitorC_2 and C_3 through switches S_1, S_2, $D_3$and D_5. The output capacitor C_0 releases energy for the resistive load R. Fig. 3 shows the operating circuit of mode 1.

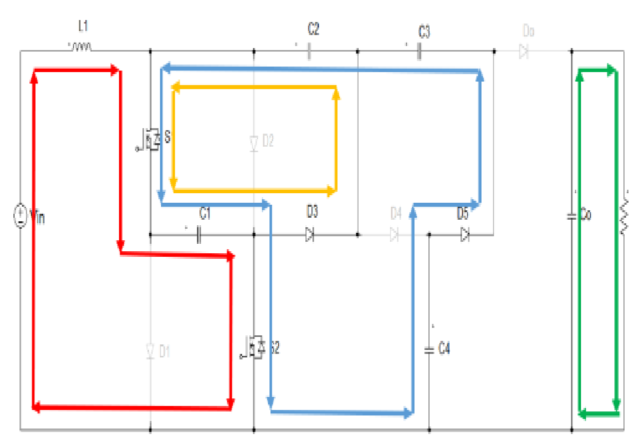

Fig. 3. Operating Mode 1

2) *Mode 2:* Within this priod the mid-diodes D_1, D_2, $D_4$and output diode D_0 are turned on while other switches S_1, S_2 and diode D_3 are turned off. At this moment, the V_{in} and L_1 charges C_1 through the D_1 and D_2. And V_{in} and L_1 together with C_2 charges C_4 through the diode D_4. Thus the inductor L_1 and capacitor C_2 discharges. At the same moment V_{in} together with L_1 , C_2 and C_3 supply energyfor C_0 and R through the output diode D_0. Fig. 4 shows the operating circuit of mode 2.

B. Design of Components

In order to operate an converter properly, its components should be designed appropriately. Some assumptions are takenfor the design of single inductor boost inverter. It consists of design of load resistance, inductor L_1 and the capacitors C_1, C_2,C_3,C_4 & C_0. The input voltage is taken as 30V. The output power and output voltage are taken as 350W and 350V.Switching frequency is 30kHz. On solving (1) output currentis obtained as 1A. So, the ripple of indutor current is taken as ΔI_L = .25 of I_o.

$$I_O = P_O / V_0 \qquad (1)$$

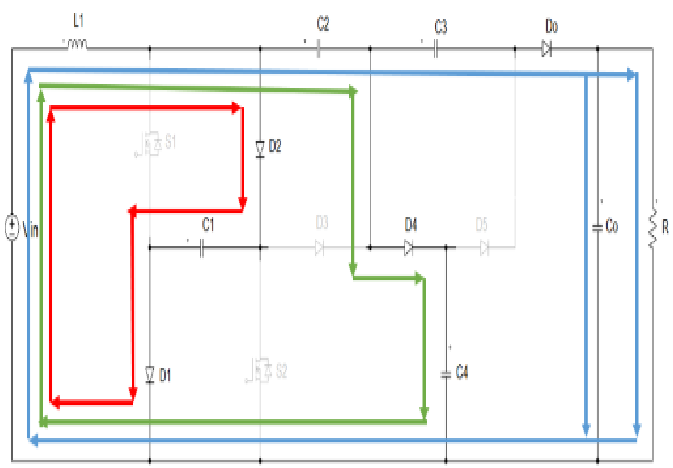

Fig. 4. Operating Mode 2

III. SIMULATIONS AND RESULTS

The modified single inductor boost converter is simulated in MATLAB/SIMULINK by choosing the parameters listedin Table 1. The switches are MOSFET with constant switching frequency of 30kHz. The both power switches are syn-chronously controlled with same duty ratio. A dc input voltage

Parameters	Value
Input voltage, V_{in}	30V
Output voltage, V_o	350V
Switching frequency, f_s	30 kHz
Rated power, P_o	340 W
Inductor, L_1	1 mH
Capacitor, C_1	20 µF
Capacitor, C_2, C_3, C_4 ,C_o	10 µF

Table 1 Simulation Parameters Modified Single Inductor Boost Converter

$$\frac{V_o}{V_{in}} = \frac{3}{(1-2D)} \qquad (2)$$

$$R_o = \frac{V_o^2}{P_o} \qquad (3)$$

Duty Ratio can be found by (2) which is taken as 0.35. Thevalue of load resistor is set as 360Ω in (3). of 30 V and input current of 14A gives an dc output voltageof 350 V and output current of 1A for an output power, *Po*of 340 W. Fig. 5 shows the input voltage and current, Fig. 6

shows the output voltage and current . Thus, the voltage gain is obtained as 1.7.

The inductor L_1 is obtained by taking current ripple as 25%of I_o. By substituting values to (4) it is approximated to 1mH.

$$l_1 >= \frac{2D*(1-D)*V_0}{3*\Delta I_{L1}*f_s} \qquad (4)$$

The design of the capacitor mainly considers the voltage stress and maximum acceptable voltage ripple across it. The capacitors C_1 C_2, C_3,C_4 & C_0 are obtained by taking voltage ripple as 10% of V_o for all other capacitors and 1% of V_o for output capacitor. By substituting values to (5), (6), (7) & (8) capacitor values are approximated to 20μF for C_1, 10μF for C_2,C_3,C_4 & C_0.

$$C_1 >= \frac{(1+D)*V_0}{(1-2D)*R*\Delta V_{C1}*f_s} \qquad (5)$$

$$C_2 >= \frac{V_0}{R*\Delta V_{C2}*f_s} \qquad (6)$$

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$$C_3 >= \frac{V_0}{R * \Delta V_{C3} * f_s} \tag{7}$$

$$C_0 >= \frac{D * V_0}{R * \Delta V_{C0} * f_s} \tag{8}$$

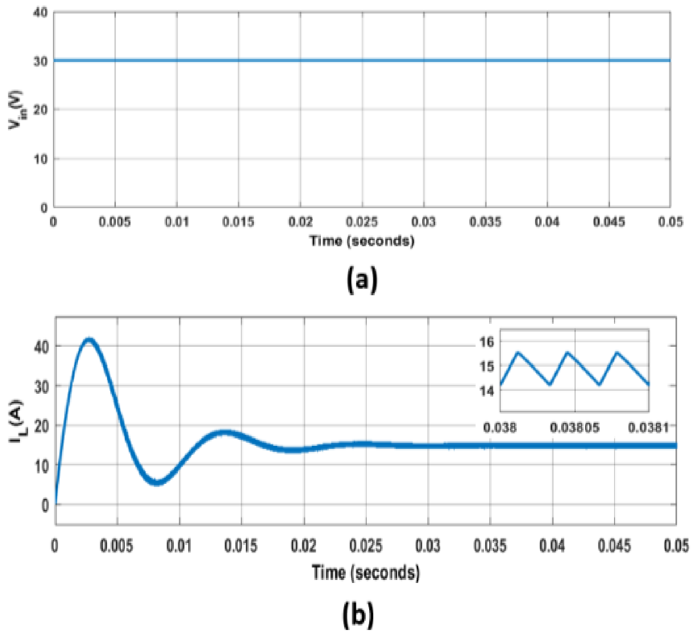

Fig. 5. (a) Input Voltage (V_{in}) and (b) Input Current (I_{in})

Fig. 7 shows the gate pulse and voltage stress across switches S_1 and S_2. Switch S_2 has the same waveform as S_1.The voltage stress of V_{S1} and V_{S2} are 96V.

The voltage across all capacitors are shown in Fig 8.It can be seen that the voltage across capacitor V_{C1} is 100V which is same as voltage across V_{C2}. The Voltage across capacitor V_{C3}

is same as voltage across V_{C4} and the value obtained is 185V. Fig. 9 shows the voltage across all diodes D_1,D_2,D_3,D_4, D_5 and D_0. The voltage across diodes V_{D1} and V_{D3} are same and the value obtained is 85V. The voltage across diode D_2 is 95V. It can be seen that voltage across D_4 is 200V and voltageacross D_4, D_5 and D_0 are same and the value obtained is 185V.

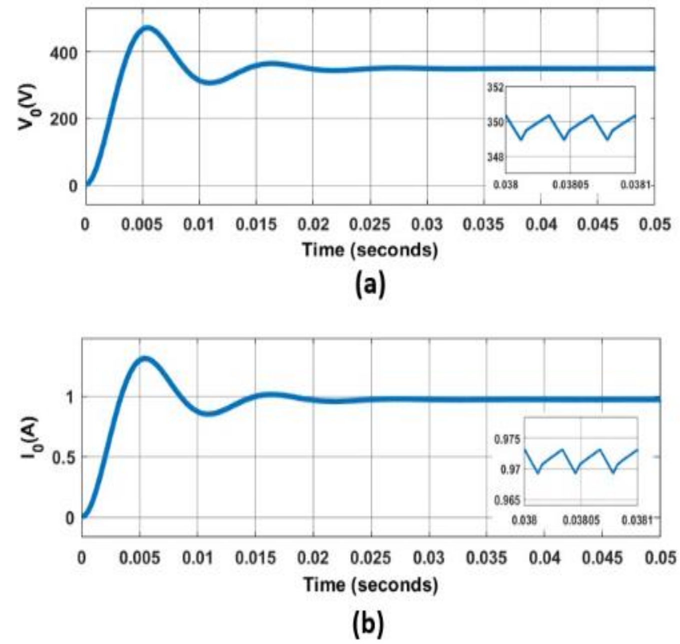

Fig. 6. (a) Output Voltage (V_0) and (b) Output Current (I_0)

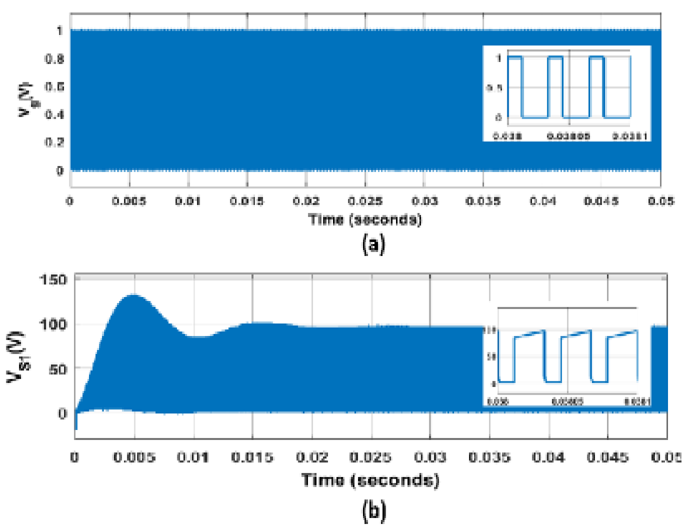

Fig. 7. (a) Gate pulse of S_1 and S_2 (b) Voltage stress of S_1(V_{S1})

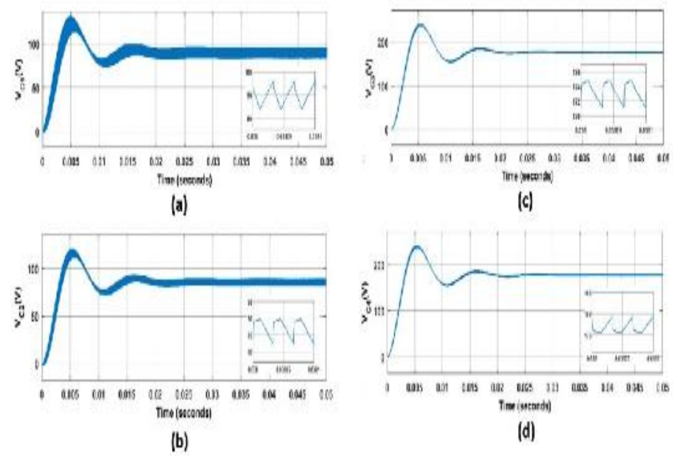

Fig. 8. (a) voltage across capacitor C_1 (V_{C1}) (b) voltage across capacitor C_2 (V_{C2}) (c)voltage across capacitor C_3 (V_{C3}) (a) voltage across capacitor C_4(V_{C4})

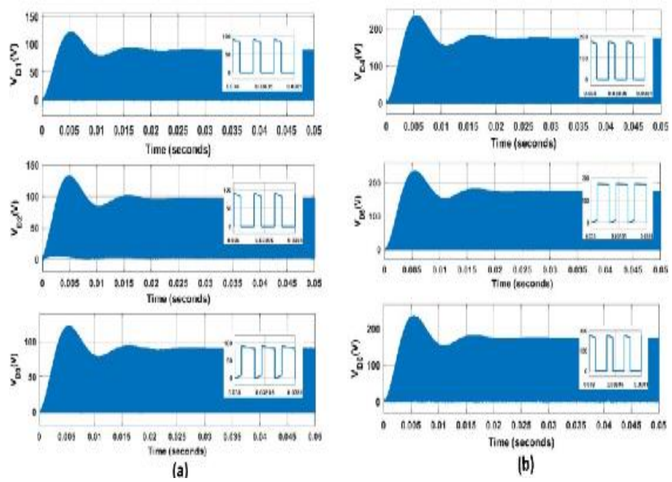

Fig. 9. (a) Voltage across diode $D_1(V_{D1})$,$D_2(V_{D2})$,$D_3(V_{D3})$ (b) Voltage across diode $D_4(V_{D4})$,$D_5(V_{D5})$,$D_0(V_{D0})$

IV. PERFORMANCE ANALYSIS

Efficiency of a power equipment is defined at any load asthe ratio of the power output to the power input. Here the efficiency Vs output power with R load and RL load for singleinductor boost converter is done and shown in Fig. 10. The maximum converter efficiency for R & RL load are obtained as83% and 85% . The variation of efficiency with power output is medium for both load ie about 340 W. Thus, the proposed boost converter can be used in medium power applications.

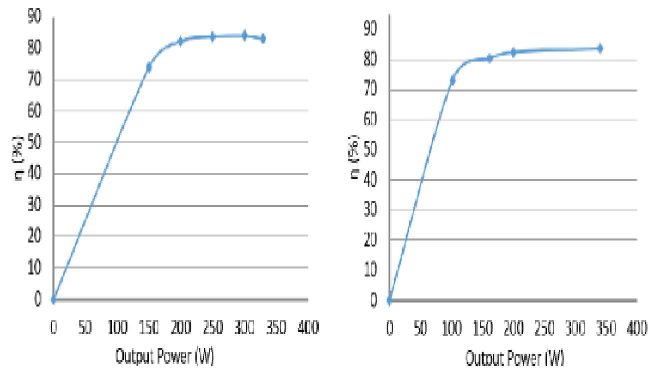

Fig. 10. Efficiency Vs Output Power for (a) R load, (b) RL load

The plot of Gain of the converter as a function of duty ratio shown in Fig. 11. By analyzing the graph it is clear thatthe voltage gain increases with Duty ratio for the proposed converter.

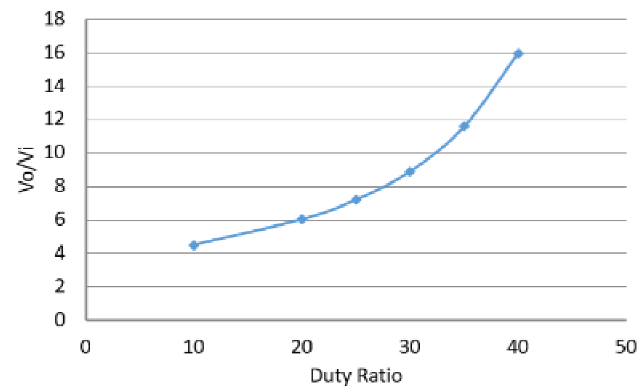

Fig. 11. Gain Vs Duty Ratio

The plot of output voltage ripple as a function of switching frequency and duty ratio is shown in Fig. 12. The outputvoltage ripple is decreased as the switching frequency is increased and output voltage ripple increases while increasing the duty ratio.

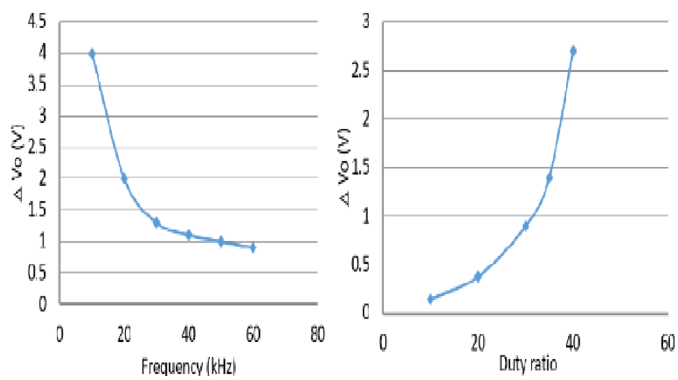

Fig. 12. Output Voltage Ripple Vs Switching Frequency and Output Voltage Ripple Vs Duty ratio

V. COMPARITIVE STUDY

The comparison between single inductor boost converter and modified boost converter is given in Table 2. From the comparison table it is clear that the modified boost converter has high gain than single inductor boost converter. The number of components higher for modified converter because of the addition of switched capacitor in boost converter. And thereby the efficiency of the converter decreased from 83% to 81%.The output voltage of the converter increased to 350V from 280V. The output voltage ripple and current ripple are reduced for modified converter. The voltage stress across switch for both the converters are same.

Parameter	Single inductor Boost converter	Modified single inductor Boost converter
Number of components	8	10
Efficiency	83%	81%
Output voltage ripple	1.4V	1.2V
Voltage gain	9.2	11.6
Output voltage	280	350V
Output current ripple	.005A	.003A
Voltage stress across switch	3.05V_{in}	3.05V_{in}

Table 2 Comparison Between Modified Boost Converter And Single Inductor Boost Converter

Table 3 Shows The Component Wise Comparison Between Mod- Ified Single Inductor Boost Converter And Other Boost ConverterTopologies.

converters	Modified boost converter	Boost converter in[1]	Z-source dc-dc converter in[2]	Dc-dc converter in[5]
Switches	2	2	1	1
Inductors	1	1	2	3
Capacitors	4	3	4	7
Diode	5	4	3	5

Table 4 Comparison Between Modified Boost Converter And Other Boost Converters

VI. EXPERIMENTAL SETUP WITH RESULT

For the purpose of implementing hardware, the input volt-age is reduced to 1.7V and the switching pulses are gener-ated using TMS320F28335 controller. The switches used areMOSFET IRF540 & diodes are IN 5817. Driver circuit is implemented using TLP250H, which is an optocoupler usedto isolate and protect the microcontroller from any damageand also to provide required gating to turn on the switches. Experimental setup of proposed boost converter is shown inFig. 13. Input 1.7V with 0.504A DC supply is given fromDC source. Switching pulses are taken from TMS controllerto driver circuit. Thus, an output voltage of 23V with 30Hzfrequency is obtained from power circuit that is shown inFig. 14. Output voltage of converter is taken from the DSOoscilloscope.

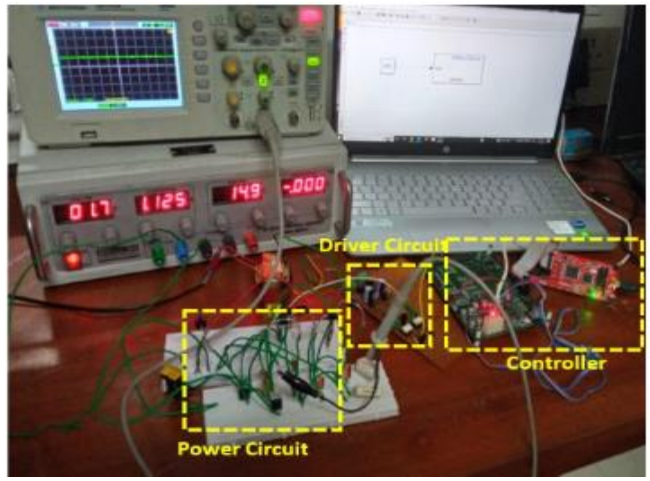

Fig. 13. Experimental Setup

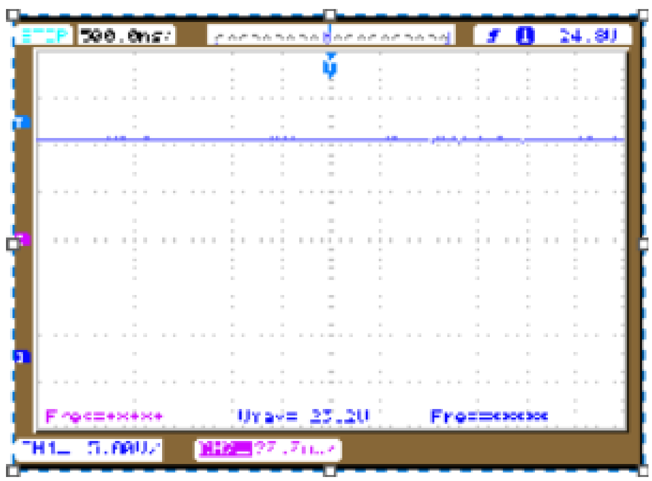

Fig. 14. Output Voltage of Proposed converter

VII. CONCLUSION

A new topology of single inductor boost converter with low ripple content and high conversion ratio is presented. Switchedcapacitor concept is adopted in order to improve the gain. The output has lower voltage and current ripple when compared with other topologies aids the converter advantage. For a powerof 340W, the system provides an efficiency of 81% with a highgain of 11.6. The control of the proposed converter is im- plemented using TMS320F28335 microcontroller. Converter prototype of 7W provides the expected performance with an output voltage of nearly 23V, considering the drop across the components. Thus the modified SLBC can be used for wide conversion range applications with high voltage gain, high efficiency, high power density, and high reliability.

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